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Norman, David W.

Monterey, California. Naval Postgraduate School

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NAVAL POSTGRADUATE SCHOOL
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THESIS

A COST ESTIMATION STUDY OF
TH-57 UPGRADE PROPOSALS

by

David W. Norman

September 1992

Thesis Advisor: Michael G. Sovereign

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A COST ESTIMATION STUDY OF TH-57 UPGRADE PROPOSALS

by

David W. Norman
Lieutenant, United States Navy
B.A., San Francisco State University, 1984

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Author: [redacted]
David W. Norman

Approved by: [redacted]
Michael G. Sovereign, Advisor

[redacted]
Cdr Frank Petho, Second Reader

[redacted]
Peter Purdue, Chairman
Department of Operations Research

ABSTRACT

This thesis uses cost estimation techniques and computer models to analyze complex issues associated with upgrading the Navy's helicopter trainer, the TH-57, which is approaching its service life limit. A decision regarding a TH-57 upgrade is needed to support the current training syllabus. The analysis revealed that without a comprehensive long range plan, the Training Command will ultimately face a no-win situation; that is, reducing either its pilot training rate or syllabus flight hours. A pilot training rate reduction will create a shortfall of fleet pilots and a flight hour reduction may adversely impact flight training quality. The problems identified in the Chief of Naval Air Training's Tentative Operational Requirement were addressed. Several aircraft configurations were evaluated and four recommendations were made to ensure an effective upgrade.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

A. BACKGROUND

The Navy's primary helicopter flight trainer is the TH-57. The trainer has been in use in different configurations since 1968. It is a derivative of a commercial version produced by Bell Helicopter Textron (BHT) and is designated the Jet Ranger Model 206B. The trainers current models, the TH-57B and the TH-57C, were delivered to the Navy in 1981. The TH-57B is the more basic of the two models and is used primarily for teaching student pilots the basics of helicopter flight, which include hovering, turns, takeoffs and landings, and autorotations.

The TH-57C is the more sophisticated model and is used for the majority of undergraduate training, including all instrument flights. This model, which was delivered first, has accumulated more flight time than the TH-57B and is approaching the Navy's self imposed 10,000 hour service life limit much sooner than the TH-57B.

An aircraft service life limit is the maximum number of flight hours an airframe is allowed to accumulate. Service life limits are established by NAVAIRINST 13130.1a. The TH-57C is nearing its service life limit and without it, the Navy's undergraduate helicopter training could not continue in

its present form. This posses a serious problem that must be solved before there is an adverse impact on the helicopter pilot training rate (PTR). The PTR is the total number of student helicopter pilots that complete training in a fiscal year. The PTR, which is expected to remain stable in the foreseeable future, has been approximately 600 students. This includes Navy, Marine Corps, Coast Guard, and international students.

B. SERVICE LIFE

Today's training fleet consists of 49 TH-57B's and 89 TH-57C's. Assuming no losses due to mishaps, the TH-57B fleet will remain at its current level until the middle of 2000. A year later, the TH-57B fleet will have over half of its airframes at the 10,000 hour limit. In 2002, 90 percent of the TH-57B's will have reached that limit. The TH-57C's will start to reach the end of their service life by the end of 1996. In 1998, over half of the TH-57C fleet will have reached their service life limit, and in 2000, only ten percent will be in service.

The 10,000 hour service life limit does not account for any aircraft losses due to mishaps. The current projected mishap rate is one aircraft loss a year. This projection uses attrition planning rates of 0.6% of the aircraft inventory per year as established by OP-05.

It should be noted that approximately ten aircraft are being transferred to Davis Mothan AFB because the current fleet size is larger than what is required to maintain the current PTR. The reason for this transfer is to reduce fleet operating costs. The transfers will have little effect on the overall rate at which the fleet reaches its service life limit, provided they are eventually returned to the inventory.

The 10,000 hour service life limit can be extended, if a Service Life Assessment Program (SLAP) has been conducted to verify that the airframe and components will last longer than 10,000 hours. The Naval Air Warfare Center (NAWC) Aircraft Division in Warminster Pennsylvania, formerly Naval Air Development Center (NADC), has submitted a proposal to conduct the SLAP. The SLAP will analyze the TH-57's current use to determine its impacts on the airframe and structural components of the aircraft. The analysis will be accomplished primarily by using stress tests. The SLAP's analyses include, but are not limited to, the airframe, flight controls, fuel system, and rotors. The results of the SLAP will determine if changes in the airframe or components are necessary to extend the service life of the aircraft.

If the SLAP indicates a service life beyond 10,000 hours is allowable, then the TH-57's future configuration will have to be determined. There are three possible outcomes. If the SLAP reveals that no modifications are necessary, the aircraft can continue to operate in its current configuration.

However, if the SLAP shows that modifications are necessary to extend the aircraft's service life, then analyses will be needed to ensure that the extra life can be gained at a cost less than the third option, which is purchasing new aircraft. Budget constraints will eliminate this option.

C. PROBLEMS

The TH-57 is a reliable, safe aircraft, but it does have significant problems that should be addressed before a decision is reached on the final configuration. In August 1990, the Chief of Naval Air Training identified eight problems in the Tentative Operational Requirement (TOR). These problems are (a) drivetrain limitations, (b) the lack of crashworthy seats, (c) the problems associated with two different aircraft configurations and their costs, (d) a restrictive maximum gross weight limitation, (e) a requirement for a Global Positioning Navigation System (GPS), (f) the lack of Night Vision Goggle compatibility, (g) the current aircraft does not meet electromagnetic interference (EMI) standards, and (h) a desire for a glass cockpit display to replace near obsolete equipment.

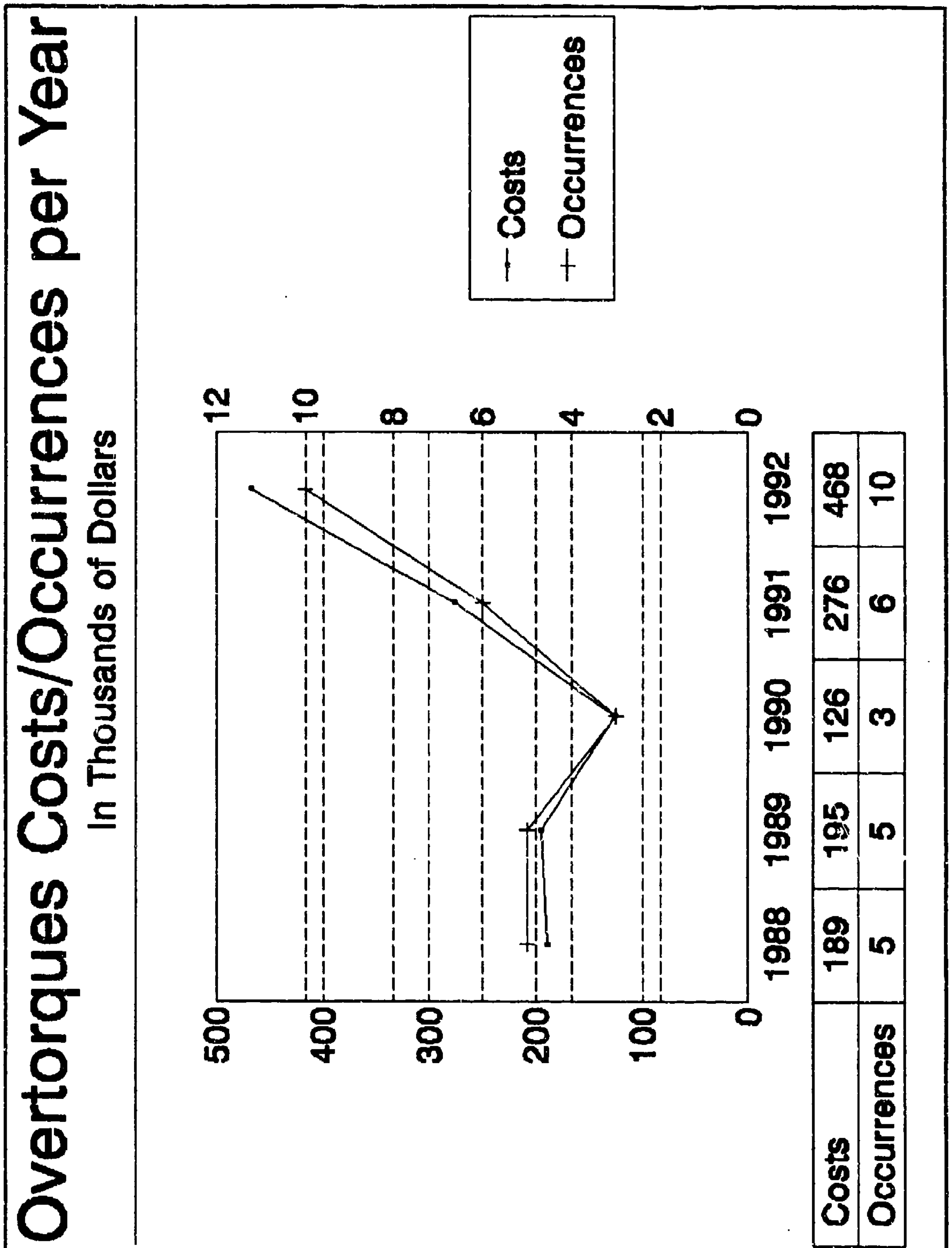
This thesis addresses these eight requirements in three broad categories. The current drivetrain limitations will be discussed first, followed by the desire for crashworthy seats, and lastly the avionics requirements. The discussion of the

avionics will encompass the Global Positioning System, Night Vision Goggle compatibility, and the glass cockpit.

Due to excessive cost, two of the eight TOR requirements will not be analyzed: EMI compliance and the single aircraft configuration. EMI compliance will not be discussed because, ensuring compliance to military EMI standards for commercial components would be prohibitively expensive for civilian vendors. Modifying the fleet to a single aircraft configuration will not be addressed, because such a modification would require all aircraft to be Instrument Flight Rules (IFR) rated. It would cost an additional five million dollars to modify the TH-57B to IFR rated aircraft.

1. Drivetrain Torque Limitations

The current drivetrain is torque limited, which along with the operating environment and mission, makes the TH-57 prone to overtorques. An overtorque arises when an excessive amount of power is applied to the aircraft's transmission. This usually occurs during the landing phase where an excessive rate of descent must be overcome to prevent a hard landing. An overtorque condition, however, can occur in any phase of flight. Figure 1 shows how the resulting maintenance and parts costs have steadily increased since 1988, The exception to this trend is 1990. In 1988, the cost due to overtorques was $180,000, and so far, the costs incurred in fiscal year 1992 are approximately $500,000.



	1988	1989	1990	1991	1992
Costs	189	195	126	276	468
Occurrences	5	5	3	6	10

Figure 1 Overtorques

2. Crashworthy Seats

A study of TH-57 mishaps shows that there have been numerous mishaps in which the aircraft survived a hard landing, but the aircrew suffered back injuries. Aircrew seats have been implicated in many of these injuries. (NADC Interim Report, p. 1, 1991) The seats in the TH-57 are not crashworthy, nor do they provide anthropometric adjustment features which would allow for the comfortable accommodation of various body configurations in the cockpit. Installing crash attenuating seats should reduce the number and severity of spinal injuries suffered in TH-57 mishaps.

Navy aircraft which have crash attenuating seats have demonstrated a need for an Inflatable Body And Head Restraint System (IBAHRS). This system was designed to reduce the unique injuries inherent with crash attenuating seats. These injuries are mainly impaling injuries in which the pilot is thrown forward and impaled on the cyclic when the seat strokes down during a mishap. Since this is a relatively new system and no data is currently available, it will not be included in this discussion.

3. Avionics Changes

The TH-57C's avionics package is scheduled to change by 1999 when the a Global Positioning System (GPS) is installed. This navigation system will be used throughout the Naval aviation community, including the Training Command. If

the SLAP indicates that a service life extension can be achieved, analyses will have to be conducted. This analysis must determine if the current avionics package will suffice, or if changes are needed to prevent the obsolescence of the avionics package.

Unless the current instrumentation becomes obsolete, the most significant benefit of the avionics upgrade will be its training impact. Having the same instrumentation in the TH-57 and the proposed Naval Primary Aircraft Training System (NPATS) obviates the need for students to relearn different avionics packages. While this contributes to better flight skills, the upgrade may also reduce the instrument flight training syllabus. The value of an avionics upgrade will be based on the cost of the upgrade and the decision maker's estimate of the worth associated with like instrumentation in all training aircraft.

II. NEED STATEMENT

A. JUSTIFICATION

One major problem during the initiation of a new acquisition program is convincing the warfare sponsor to fund the program. The TH-57 and the fixed-wing trainer, the T-34, present a unique situation because they are commercial aircraft maintained by commercial contractors to commercial (Federal Aviation Administration) standards. This has led some to believe that the Navy's 10,000 hour service life limit should not be applied to the TH-57. Bell Helicopters Textron (BHT) does not recognize a service life limit on their civilian version, the Jet Ranger Model 206B. The 3,797 Jet Rangers produced by BHT have more than 24 million hours on them, and one airframe has more than 29 thousand hours on it. On this basis alone, a waiver of the service life limit might be considered reasonable.

The Training Command, however, puts different types of stresses on its airframes which are generally considered more severe than the stresses imposed on civilian aircraft. At this point, it is important to distinguish between component and airframe. Stress to an airframe is partly caused, or at least is affected, by its components. The big difference between the military and civilian flight environments is the

number of high stress maneuvers routinely performed in the Training Command. These maneuvers affect the airframe and through it, the aircrafts' components. These maneuvers include; autorotations, running landings, and cut guns.[1]

The debate on the demands imposed by different flight environments may continue, but as it does, flight time will accumulate on the TH-57 fleet. This may adversely impact the PTR. Assuming the service life limit will not be waived, a schedule must be made to accommodate any possible rework that results from the SLAP study. The airframes will start to reach the end of their service life limit in 1996. Since NAWC's proposed SLAP will take five years to complete, a rework plan must be formulated that prevents a negative impact on the PTR due to a lack of aircraft.

Figure 2 shows that a severe lack of TH-57C airframes starts at the end of 1997. The proposed SLAP will not be completed at the end of 1997, even if it is started in 1993. Less then half of the TH-57C airframes will be available by

---

[1] An autorotation is a maneuver in which the engine power is reduced to idle to simulate a loss of the engine, and a landing without the benefit of the engine is conducted. If executed correctly, the resulting landing is no more stressful on the aircraft than a normal powered landing. A running landing is a maneuver in which a landing is conducted by sliding the aircraft along the ground to a stop. A cut gun is a maneuver in which while in a hover, engine power is reduced to idle and the aircraft is allowed to settle on the ground. Like the autorotation, if executed correctly, this is no more stressful than a normal landing. However if it is not executed properly, the resulting impact with the ground can be quite severe.

the end of 1998. This situation increases the odds of failing to attain the PTR. The failure will become apparent in the instrument training portion of the syllabus, because these training flights can not be flown in the TH-57B.

B. DEVELOPMENT

A Fortran program was written to estimate the aircraft availability per month starting in January 1992, and continuing for the next eleven years. Availability estimates highlight the consequences of postponing a decision on whether or not to start the SLAP or instead, obtain a waiver of the service life limit.

Cost estimation techniques were used to derive a cost benefit estimate for several possible components from different companies that would satisfy the TOR's requirement. These estimates and components' physical weights were used in an optimization model to determine how to best configure an updated TH-57B and TH-57C.

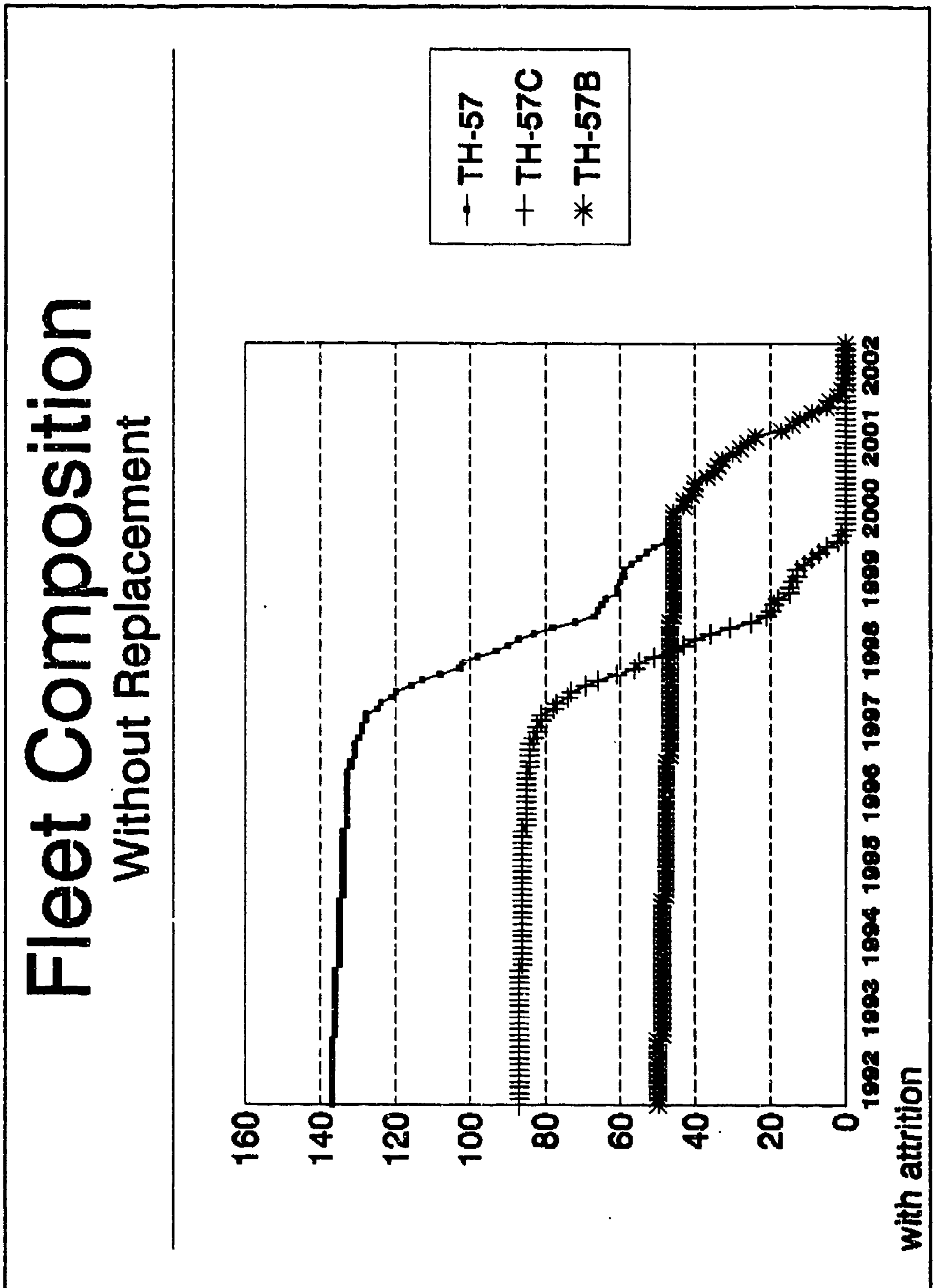


Figure 2 Aircraft Attrition

III. METHODOLOGY

Two data sets were collected to demonstrate the use of three analytical techniques: (a) a Fortran model that generates fleet compositions under various parameters, (b) cost estimation techniques that estimate the benefit of a component change for various time periods, and (c) an optimization model that selects the optimal mix of aircraft components given the cost benefit and weight of each component. The two data sets will be described in the next section, followed by discussions of the three analytical techniques.

A. DISCUSSION OF DATA

1. Aircraft Related Data

The first data set was used in the Fortran model. This data is mainly aircraft related. The number of aircraft used in the model was the number of aircraft currently in the Training Command fleet. The flight hours for each aircraft are as of 17 December 1991, and were obtained from NAWC. The 10,000 hour service life limit is a constant. Monthly flight averages per aircraft model were also obtained from NAWC. Rework time was varied from one to six months. Each of these

variables can be easily changed in the model to test alternative hypotheses.

2. Cost Estimation Data

The second data set was used for the cost estimation and optimization techniques. This data was obtained primarily from various commercial vendors and Navy sources. No attempt was made to verify the accuracy of the cost and weight data obtained from each vendor. There was insufficient information available to give the vendors an accurate estimation about how many components would be required, and what changes to the airframe would be needed to incorporate the changes, if any.

If the vendors were asked to provide accurate estimates, they would consider those estimates proprietary, and withhold the information. Therefore, vendors were asked to provide the data as best estimates. The data obtained from the Navy for this set was taken from the TOR and is not meant to represent the Navy's final requirement for the TH-57.

Table I shows the cost and weight data for various components. No vendor's names or component names will be used to describe these components to overcome proprietary concerns. Additional "dummy" data will be used in the optimization model to demonstrate selected features of the model. "Dummy" data is hypothetical data which is used to provide additional components with various attributes in the optimization model.

This allows the model to simulate additional components which have not yet been identified by the Navy or other vendors.

Table I. COMPONENT DATA

Component	Name	Cost	Weight
Seats	Seat1	$ 30,000	22 lbs
Drivetrain	DT1	$ 89,000	14 lbs
	DT2	$ 250,000	100 lbs
Avionics	AV1	$ 100,000	70 lbs
	AV2	$ 180,000	113 lbs
	AV3	$ 250,000	60 lbs

B. FORTRAN MODEL

1. Model Development

The Fortran model was developed to predict how many TH-57B's and TH-57C's will be in service during any month. The model incorporates and allows for the variation of (a) PTR, (b) total aircraft in the Training Command fleet, (c) attrition rate, (d) rework time, (e) baseline flight time of all aircraft, and (f) monthly flight time. The particularly interesting parameter is "rework time" because it has the greatest effect on the size of the fleet. Appendix A contains the Fortran code of this model.

2. Assumptions

Six assumptions were made to formulate the Fortran model. A discussion of each assumption and its justification follows.

a. *Tracking Individual Airframes*

Tracking individual airframes was not attempted. It is irrelevant when a particular airframe reaches its service life limit, only that it is reached. The time a particular airframe reaches its service life limit may change drastically due to unforseen maintenance or arbitrarily low utilization for many months. This is not a problem however, because other airframes will make up the temporary difference, and in time, a low use aircraft will become a high use aircraft.

b. *Attrition*

Attrition is accounted for in the model by striking one airframe per year using OP-05's planning factor of 0.6% of inventory annually. Attrition occurs at the first of each year to produce the worst possible scenario, and alternates between the TH-57B and TH-57C fleets.

c. *Rework Time*

Rework time was held constant throughout the entire fleet. Rework time is the period of time an aircraft is unusable to the Training Command. It is the period between reaching its service life limit, and its return and acceptance by the Training Command. Inherent in this assumption is that

the rework facility can accept an aircraft within the month of its reaching its service life limit. Rework time was varied from one to six months in the model.

d. Aircraft Requirements

The number of aircraft required is equal to the Primary Aircraft Authorized (PAA), plus the number authorized in excess of the PAA. The number authorized in excess of the PAA is equal to 1.3 percent of the PAA. The number of aircraft required equals 118 plus two, for a total of 120. The PAA is calculated by multiplying the PTR by the syllabus length in hours and by the overhead rate of 1.2678, and dividing that total by the aircraft utilization rate.

$$PAA = (PTR \times Syl.length \times overhead) / util.rate$$

The overhead rate is the total number of flight hours put on the aircraft during a student's training, divided by the total number of flight hours in the flight syllabus. This accounts for student training, reflights for a student who is having difficulties, instructor training, maintenance flights, and VIP flights. This rate is currently 1.2678 and is provided by OPNAV. The aircraft utilization rate is 720 hours per year, also provided by OPNAV.

e. Flight Time

Monthly flight time will remain constant at 52 hours per month per aircraft. This level assumes a stable

PTR. Storing aircraft at Davis Mothan AFB will not significantly affect this level, since the transferred aircraft currently total less than eight percent of the fleet. The corresponding increase in the monthly flight time per aircraft is only four hours.

f. PTR

The PTR was held constant through the entire 11 year period. PTR data is only available over a five year projection. Historically, it has not varied greatly from current levels. Holding the PTR constant may not seem to be a good assumption due to the downsizing of the Navy, but the downsizing will occur mainly in the decommissioning of many support ships and in the number of aircraft carriers in operation. There are very few helicopters on board carriers and the support ships marked for decommissioning will be older ships that do not have helicopter support facilities. Also, with the current Navy pilot retention rate of only 35 percent, the PTR must stay high too ensure enough pilots remain in the fleet to meet mission requirements.

3. Output

The model's output is a monthly breakdown of total aircraft available, by model type, using December 1991 baseline data. Figure 3 shows the monthly fleet composition of TH-57Bs and TH-57Cs for a four month rework time. Figure 4 shows the monthly fleet composition for a six month rework.

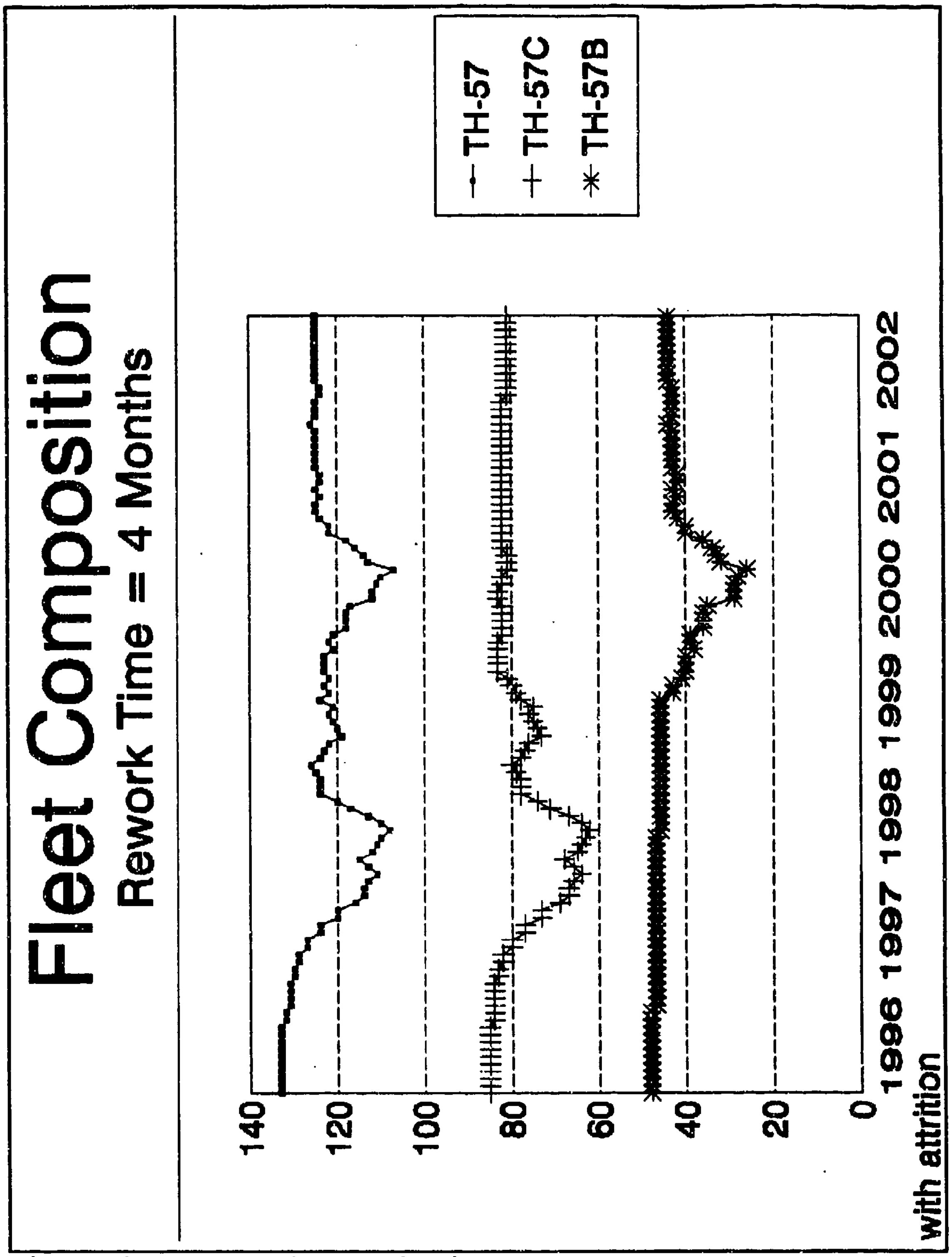


Figure 3 Four Month Rework Time

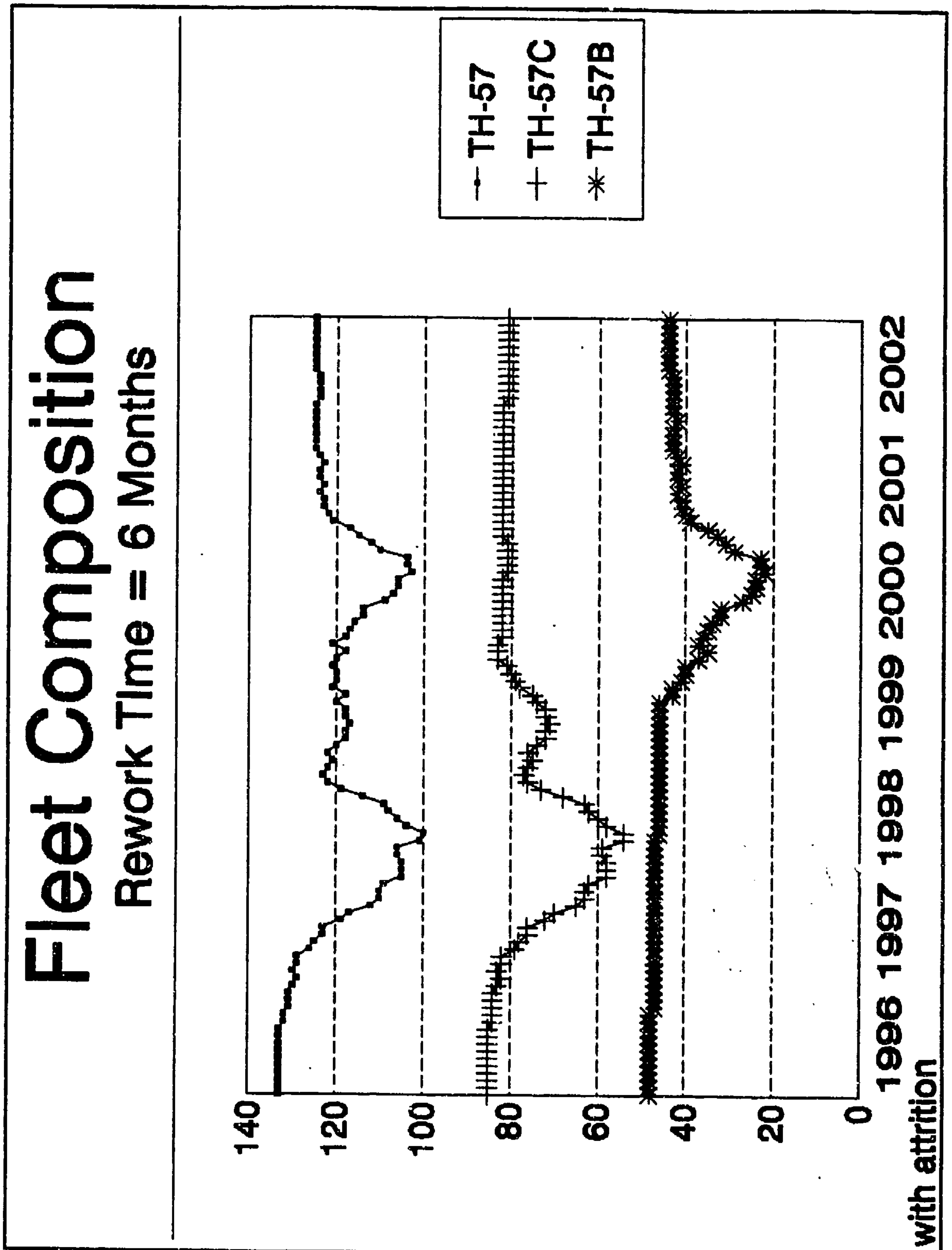


Figure 4 Six Month Rework Time

The output incorporates the current attrition rate, but does not account for any aircraft removed from the fleet for any other reason.

C. COST ESTIMATION

Cost estimation techniques were used to determine the cost benefit of using a particular vendor's component. Since all component data was proprietary, all cost data used were provided by the vendor. These estimates do not include learning curves, installation, or large purchase discounts. Standard present value calculations for five, ten, and 15 years were used with an interest rate of 10 percent.

1. Crashworthy Seats

In the case of crashworthy seats, benefits were calculated by averaging costs to the Navy from 1981 to the present. This includes (a) estimated medical costs attributable to an aircraft mishap, (b) the loss of an instructor or student from the Training Command, and (c) the loss to the Navy of flight pay to the aircrew during time spent temporarily in a nonflight status.[2]

[2] This does not include the one aircrewman who was cited in the NADC Interim Report of 1991 as waiting eight months for back surgery. Complete cost data for this aircrewman's injuries were not available in time for inclusion into this thesis.

2. Overtorques

The maintenance and parts costs associated with overtorques for 1992 were used to develop the benefit per year for drivetrain improvements. This benefit was divided by the total number of aircraft in the fleet to derive a per aircraft benefit for each year.

3. Avionics

For the avionics benefit, a sensitivity analysis was used to determine the minimum allowable benefit needed to economicallyjustify a change in the avionics. The Training Command must determine whether this benefit can be attained by the elimination of instrument training flights from the syllabus, the elimination of ground school time, or simulator training instruction.

D. OPTIMIZATION MODEL

1. Model Development

The commercial computer program GAMS was used to build an integer optimization program. The model used the results obtained from preceding cost estimation techniques, and data provided by vendors of the potential component changes. The model selected a mix of components that maximized the value of the benefits from the component changes minus the components costs.

2. Constraints

The model's only constraint was the weights of the components. The potential changes made to this aircraft cannot increase its weight above which it cannot conduct its mission. This constraint was set by the Chief of Naval Air Training in the TOR.

3. Output

Appendix C contains the optimization model's output. The aircraft's configuration and cost will be discussed in the following chapter.

IV. ANALYSIS OF RESULTS

A. FLEET COMPOSITION MODEL

The model was run while varying rework times from one to six months. The results showed that until the rework time was four months or greater, there was no impact on the PTR due to the reduction of aircraft below the 120 required to maintain the PTR. Assuming a rework time of four months, the fleet will lose at most 16 percent of its inventory in the second half of 1998, and this deficiency will extend through the first half of 1999. This shortfall can be compensated by flying an aircraft average of 63 hours a month. However, the major problem will be losing up to 30 percent of the TH-57C fleet which will be in rework in this time period. This loss cannot be made up by the TH-57B.

A "bottleneck" will occur in the instrument training phase for one year. The TH-57B fleet will lose a maximum of 44 percent during the 12 month period starting in the second half of 2001. This loss will not affect the PTR as much as the loss of the TH-57C, because during the same time, the TH-57C fleet will have at most, one aircraft in rework during any month. Any flight conducted in a TH-57B can be done by the TH-57C.

As the time required for rework reaches six months, the losses for the TH-57 fleet approach 22 percent in the second half of 1998, through the first half of 1999. The TH-57C fleet will lose up to 34 percent in the same time period. The TH-57B fleet will lose between ten and 46 percent of its aircraft during the 24 months starting in the second half of 2000 and extending through the first half of 2002.

B. COST ESTIMATION

The costs of overtorques occurring in fiscal year 1992 were used to calculate the benefits associated with a drivetrain upgrade. The fiscal year was not complete at the time of this analysis. However, with only two months remaining in the year, and given that past data does not suggest an increase in the number of overtorques over what has already occurred, the data was used as a baseline.

The benefit was calculated by taking the costs of the overtorques for 1992, and dividing it by the total number of aircraft in the TH-57 fleet. This equates to $3,391 per aircraft per year if all overtorques were eliminated. Since this is not likely even in the best of the drivetrain upgrades, a reduction of this value is applied for each drivetrain component. The reduction can vary for every possible component change. These values will have to be stated for each component by the vendor. Estimated values

will be used in this report because this vendor supplied data is unavailable.

Using the standard present value calculation of

$$PV = 1/(1 + .1)^n$$

where n equals the number of years being calculated, and summing the years from one to n, the five, ten, and 15 year present value numbers are 3.791, 6.145, and 7.606, respectively. Multiplying these present values by their associated cost benefits of each component, gives the maximum cost for each component that will allow a break-even point. For the avionics cost benefit, each component's cost was used as a starting point and the present value equation was solved algebraically to obtain the cost benefit required to achieve a break even point.

The Navy's cost per flight hour for the TH-57 is approximately $240. If the Training Command can justify a reduction of a two hour flight in the instrument training phase, this equates to a total fleet-wide reduction of 1150 hours, assuming a PTR of 575. This yields a savings of 8.3 hours per aircraft, which corresponds to a savings of $2,000 per aircraft per year, or $276,000 for the fleet. This savings is well below the break even point for a positive cost benefit of an avionics upgrade, even at the 15 year period.

Table II shows the present value calculations for five, ten, and 15 years for each component. The total cost benefit per aircraft per year is $16,560. The corresponding fleet-wide benefit is $2,285,280. This includes the actual benefits of improving the aircraft's seats and drivetrain, plus the derived benefit of the avionics upgrade. The cost for these components is $219,000 per aircraft. The fleet-wide cost is $30,222,000.

Table II. BENEFITS PER COMPONENT

Comp	Benefit	% of Benefit	5 year PV	10 year PV	15 year PV
Seat1	$21	1.00	80	129	160
DT1	$3391	.50	6428	10419	12896
DT2	$3391	.75	9641	15628	19344
AV1	$23666	1.00	89716	145425	180000
AV2	$13148	1.00	49842	80791	100000
AV3	$32869	1.00	124606	201979	250000

C. OPTIMIZATION MODEL

The GAMS optimization model used the present value calculations from the previous section and the weights of the proposed components to determine the optimal mix of components to install on the TH-57. Assuming the benefits of the

crashworthy seats and the avionics upgrade can be justified by the Training Command, the optimization model showed that the upgrades can be installed within the weight constraints. Choosing the crashworthy seat (Seat1), the drivetrain component (DT1), and the avionics upgrade (AV1) would require expending $76,104 per aircraft for a total cost of $94,216,752 over fifteen years. This equates to $6,281,117 per year for fifteen years.

V. CONCLUSIONS

A. FLEET COMPOSITION

Figure 2 shows the rate of loss of the TH-57 fleet without any rework plan. Figure 4 shows the fleet composition with a rework time of six months. The Fortran model demonstrated that without comprehensive, long range planning, the Training Command will not be able to meet its PTR in the near future. This will adversely impact fleet squadrons a few years after the PTR shortfall due to a lack of replacement pilots. Although the problem will cease to exist if the service life limit is waived, the likelihood of this occurring is remote, and ignoring the service life limit is potentially catastrophic. Comprehensive planning must be undertaken to ensure that any rework plan selected does not negatively impact the Training Command's PTR.

B. COST ESTIMATION AND OPTIMIZATION

This thesis estimated the cost effectiveness of the proposed TH-57 upgrades. Besides a proposed change's cost effectiveness, its nonmonetary aspects and how they can influence a cost benefit decision must also be considered. These aspects are subjective, but nonetheless, have operationally significant impacts. Safety is one such aspect. Ultimately, safety's effect on the TH-57's final configuration

will be determined by the utility ascribed to it by the decision maker.

Of the components with known benefits; that is, the drivetrain upgrade and the crashworthy seat, the differences between the costs and benefits is smallest for the seat. A drivetrain upgrade provides the largest monetary benefit, while the avionics upgrade is the most expensive component to change. *To achieve a meaningful cost effective benefit for the avionics components, a significant modification to the training syllabus will be required.* Even if the NPATS avionics system was installed on the TH-57, the upgrade may not be able to justify the required syllabus change. That change would not be trivial.

The syllabus change required by the avionics upgrade would reduce instrument flight time. Flight time associated with the syllabus' instrument training stage not only enables students to familiarize themselves with the avionics, it also gives them time to master the instrument flight maneuvers. The Training Command will have to determine if reducing flight hours from the instrument stage of the syllabus can be justified. The trade-off facing decision makers is clear. *It is a trade-off between reducing flight hours or failing to attain the projected PTR.* Is the reduction of instrument flight time associated with the avionics upgrade worth maintaining the PTR with the shortfall of TH-57C's during their rework period?

1. The Cost of Safety

This thesis has focused on the financial aspect of making changes to the existing aircraft's configuration. However, safety considerations must also be addressed. How much does safety cost, and how much is it worth? A crashworthy seat may not be a cost effective upgrade, but is cost effectiveness the only criterion for the installation of safety equipment? That the Navy's Training Commands are extremely safe flying environments is the principle reason that medical costs associated with mishaps are low. However, it would cost the Navy approximately $4,140,000 to replace the current aircraft seats with crash attenuating seats. Although four million dollars is a substantial expenditure, a few mishaps with aircrewmen suffering permanent disabilities could conceivably cost more. This factor must be included in the cost benefit analysis before a final decision on the seats can be made.

2. Feasibility

The cost estimation and optimization analyses showed that unless there is a major financial advantage to making an avionics change, or that the costs of such an upgrade are drastically reduced, a financial benefit will not be realized by making the change. The financial benefits of an avionics upgrade can be obtained only by reducing syllabus flight hours or aircraft simulator and ground school training.

At a savings of $2,000 per aircraft, per year, per two hour syllabus flight reduced, at least 6.5 flights will have to be deleted from the current training program for the least costly avionics upgrade to be cost effective. For the most expensive avionics upgrade, 16.5 flights will have to be deleted from the syllabus. This equates to cutting 13 and 33 syllabus flight hours, respectively. As previously discussed, the Training Command will have to make this a trade-off between cutting flight hours and making PTR.

3. Recommendations

The TOR gives an estimate of $294,000,000 for procurement and five years of system operation. The final total for the three upgrades discussed in this thesis was $25,222,000 for upgrading the fleet of TH-57's. The proposed SLAP's cost is $19,362,000. This allows over $230,000,000 for rework costs, new simulators, and the necessary student training equipment. Assuming the TOR's figures actually indicate budgeted funding for a TH-57 Service Life Extension Program (SLEP), the TOR's goals could be easily met, provided that no unanticipated requirements are discovered during the SLAP.

Based on the cost estimation, optimization, and numerical analysis, four recommendations are offered.

- **Install Seat1, DT1, and AV1.**

- **Install the crashworthy seat.** Base its installation on safety, not cost effectiveness.

- **Do not install the full avionics upgrade on the TH-57B.** Only the GPS needs to be installed. An additional five million dollars will be needed to upgrade the TH-57B with a full avionics package.

- **Start comprehensively planning for upgrading the TH-57.** This should be initiated as soon as possible to prevent a negative impact on the helicopter PTR.

APPENDIX A. AIRCRAFT DATA

HOURS REMAINING

TH-57B

4158.7	3885.3	3788.5	4559.4	4249.3	3875.5	4306.0	3728.4	4479.5
3975.2	4425.8	4451.8	4224.1	3716.5	3835.9	4310.8	4235.7	4561.2
4068.1	4084.9	4093.5	3916.2	3684.1	3380.4	3881.5	4546.3	4065.4
3838.7	4124.3	3926.5	3908.3	3720.0	2928.4	2591.3	3553.9	3976.7
3894.4	3215.9	3824.8	3662.2	3932.3	3677.5	3789.7	3643.9	3552.1
3462.3	3166.6	3592.4	3909.2	3692.6				

TH-57C

3782.4	5654.3	5980.7	5087.4	5580.1	6374.0	6470.3	5780.5	6142.2
5554.2	5599.4	5872.6	6663.7	5869.3	5919.3	5662.5	5829.2	5833.4
6290.8	6317.6	6406.5	5594.5	6086.0	5579.5	6270.6	4787.5	4901.2
5612.2	5620.4	5736.1	6105.6	6171.0	4978.2	6919.7	5706.1	6045.8
6270.0	6028.1	5676.9	5686.9	5784.1	6235.2	5461.8	5935.6	5923.7
6051.3	5666.3	5343.5	5563.9	5828.9	5867.8	5860.8	6044.6	5421.0
6168.5	6587.5	5238.7	6065.7	5606.7	6149.6	5650.5	5326.8	6048.6
5525.4	5585.6	6067.4	6171.3	5731.7	6027.2	5852.7	5770.4	5913.5
6084.7	6371.5	4904.7	4689.3	4863.8	5013.1	4959.5	4935.6	5197.3
5021.1	4176.9	5372.5	4689.3	4823.1	5096.5	4741.0		

APPENDIX B. FORTRAN MODEL

```
* THE FOLLOWING FORTRAN PROGRAM COMPUTES TOTAL AIRCRAFT
* AVAILABLE IN THE TRAINING COMMAND'S FLEET.  IT WILL COMPUTE
* THESE TOTALS FOR THE TH-57B,TH-57C, AND BOTH AIRCRAFT MODELS
* COMBINED.

      PROGRAM FLEET COMPOSITION
      INTEGER A, B, C, D, G, I, J, K, L, M, N, O, P, Q, R, S,
      INTEGER T, V, Z, MFT, CT(168), TH(138), ML(138)
      INTEGER TA(138,168)
      REAL    F, HOURS

************************************************************

* N AND I ARE COUNTERS, WHILE MFT IS THE MONTHLY FLIGHT HOUR
* AVERAGE, AND R EQUALS THE REWORK TIME IN MONTHS.

      N=0
      I=0
      MFT=60
      R=6

************************************************************

* THIS MAKES THE TH ARRAY, WHICH IS THE ARRAY THAT CONTAINS
* THE TOTAL HOURS ACCUMULATED ON EACH AIRCRAFT.

      DO 10 C=1, 138
         TH(C)=0
10    CONTINUE

************************************************************

* MAKING THE ML ARRAY, WHICH IS THE ARRAY THAT WILL CONTAIN
* THE MONTHS OF FLYING LEFT ON EACH AIRFRAME GIVEN THE MFT.

      DO 20 A=1, 138
         ML(A)= 0
20    CONTINUE

************************************************************

* MAKING THE TA ARRAY, WHICH IS THE ARRAY WHO'S CELL'S WILL BE
* INITIALLY BE FILLED WITH 1'S.

      DO 30 A=1, 138
         DO 40 B=1, 168
```

```
          TA(A,B)=1
40      CONTINUE
30    CONTINUE

*************************************************************

* THIS OPENS AND READS THE APPROPRIATE FILES TO BRING IN THE
* AIRCRAFT FLIGHT HOURS FOR THE TH-57B, TH-57C, AND BOTH
* COMBINED.  THIS ALSO CREATES THE OUTPUT FILES

      OPEN (UNIT=8, FILE='/CHARLIE DATA', STATUS='OLD')
      OPEN (UNIT=11, FILE='/CHAROUT DATA', STATUS='NEW')
      OPEN (UNIT=8, FILE='/BRAVO DATA', STATUS='OLD')
      OPEN (UNIT=11, FILE='/BRAVOOUT DATA', STATUS='NEW')
      OPEN (UNIT=8, FILE='/BOTH DATA', STATUS='OLD')
      OPEN (UNIT=11, FILE='/BOTHOUT DATA', STATUS='NEW')

5     READ (8,*,END=9) HOURS
           N=N+1
           I=I+1
           TH(I)=HOURS
      GO TO 5
9     CONTINUE

*************************************************************

* THIS FILLS THE ML ARRAY WITH THE MONTHS OF FLIGHT TIME
* REMAINING ON EACH AIRFRAME

      DO 50 K=1, 138
         L=TH(K)
         ML(K)=INT((10000 - L)/MFT)
50    CONTINUE

*************************************************************

* THIS LOADS THE TA ARRAY WITH A O WHEN AN AIRCRAFT HAS HIT
  ITS' SERVICE LIFE LIMIT AND FOR AS LONG AS IT IS IN REWORK.

      DO 60 O=1, 138
         M=ML(O)
         DO 70 P=M, M+R
            TA(O,P)=0
70       CONTINUE
60    CONTINUE



*************************************************************
```

```
* THIS RUNS THE COUNTER WHICH SUMS EACH COLUMN OF THE TA
* ARRAY, WHICH REPRESENTS HOW MANY AIRFRAMES ARE IN A FLYING
* STATUS.

      DO 80 T= 1, 168
         COUNTER(T) = 0
         DO 90 S= 1, 138
            COUNTER(T) = COUNTER(T) + TA(S,T)
90       CONTINUE
80    CONTINUE

************************************************************

* THIS SETS THE PARAMETERS FOR THE INDIVIDUAL MODELS

* FOR TH-57B  AND TOTAL FLEET CALCULATIONS, REMOVE THE STAR
* FROM THE BEGINNING OF THE NEXT LINE.

*     F=.0


* FOR TH-57C CALCULATIONS, REMOVE THE STAR FROM THE BEGINNING
* OF THE NEXT LINE.

*     F=.5

      G=0
      Q=138-N
      WRITE (11,*) 'R=',R
      WRITE (11,*) ' '
      Z=1991


* THIS SENDS THE OUTPUT TO THE OUTPUT FILE.

      DO 100 V=1, 156, 12
         Z=Z+1

* FOR THE TH-57 DATA, REMOVE THE STAR FROM THE BEGINNING OF
THE  * NEXT LINE.

*        F=F+1
*        G=F

* FOR THE TH-57B AND TH-57C DATA, REMOVE THE STAR FROM THE
* BEGINNING OF THE NEXT LINE .

*        F=F+.5
*        G=INT(F)

         D=G+Q
```

```
      WRITE (11,*) 'FOR THE YEAR OF',Z
      WRITE (11,*) ' '
      WRITE (11,*) CT(V)-D, CT(V+1)-D, CT(V+2)-D, CT(V+3)-D,
      +           CT(V+4)-D, CT(V+5)-D
      WRITE (11,*) CT(V+6)-D, CT(V+7)-D, CT(V+8)-D, CT(V+9)-
      +           D, + CT(V+10)-D, CT(V+11)-D

      WRITE (11,*) ' '
      WRITE (11,*) ' '
100   CONTINUE

**************************************************************

      END
      STOP
```

APPENDIX C. OPTIMIZATION MODEL

```
*This is the beginning of the TH-57 optimization model. The
*seats are listed as pairs, everything else is a single item.

SETS     I  all possible changes  /seat1,dt1,dt2,av1,av2,av3/
         J  classification of changes
                                  /seats,drivetrain,glasscp/

PARAMETERS  WEIGHT(I)  weight in pounds

    /seat1  22
     dt1    14
     dt2    37
     av1    70
     av2   113
     av3    60/;

PARAMETERS  COST(I)  cost in dollars

    /seat1  30000
     dt1    89000
     dt2   130000
     av1   100000
     av2   180000
     av3   250000/;

PARAMETERS  BENEFIT5(I)  the PV benefit of 5 years of chosing
                          change I

    /seat1  14953
     dt1     6428
     dt2     6428
     av1    49842
     av2    89716
     av3   124606/;

PARAMETERS  BENEFIT10(I)  the PV benefit of 10 years of
                          chosing change I

    /seat1  24237
     dt1    10419
     dt2    10419
     av1    80791
     av2   145425
     av3   201979/;
```

```
PARAMETERS   BENEFIT15(I)   the PV benefit of 15 years of
                            chosing change I

    /seat1  30000
     dt1    12896
     dt2    12896
     av1   100000
     av2   180000
     av3   250000/;


PARAMETERS  REQ(I,J)  equals 1 if poss. change I is in type of
                       change J

    /(seat1).seats                     1
     (dt1,dt2).drivetrain              1
     (av1,av2,av3).glasscp             1/;

SCALARS  W  max allowable weight that can be added to the
            aircraft /218/
         C  max amount that can be spent on the aircraft
            /500000/;

VARIABLES

     X(I)       1 if component I is chosen
     Z          cost per aircraft given PV of 5 years
     K          cost per aircraft given PV of 10 years
     H          cost per aircraft given PV of 15 years

BINARY VARIABLE X;

OPTION OPTCR = 0

EQUATIONS

     BENYS5       total benefit in dollars for 5 years
     BENYS10      total benefit in dollars for 10 years
     BENYS15      total benefit in dollars for 15 years
     POUNDS       observing weight limitations
     SELECT       observing logical limitations;

     SELECT(J)..    SUM(I $REQ(I,J) ,X(I))             =E= 1;
     POUNDS..       SUM(I, WEIGHT(I)*X(I))             =L= W;
     BENYS5..       SUM(I, BENEFIT5(I)*X(I) - COST(I)*X(I))
                    =E= Z;
     BENYS10..      SUM(I, BENEFIT10(I)*X(I) - COST(I)*X(I))
                    =E= K;
     BENYS15..      SUM(I, BENEFIT15(I)*X(I) - COST(I)*X(I))
                    =E= H;
```

```
MODEL OPT /ALL/; SOLVE OPT USING MIP MAXIMIZING Z;
                 SOLVE OPT USING MIP MAXIMIZING K;
                 SOLVE OPT USING MIP MAXIMIZING H;

DISPLAY POUNDS.L, Z.L, K.L, H.L;
```

APPENDIX D. OPTIMIZATION OUTPUT

C o m p i l a t i o n

```
*This is the beginning of the TH-57 optimization model.
 The seats are
*listed as pairs, everything else is a single item.

SETS     I  all possible changes
            /seat1,dt1,dt2,av1,av2,av3/
         J  classification of changes
            /seats,drivetrain,glasscp/

PARAMETERS  WEIGHT(I)  weight in pounds

    /seat1  22
     dt1    14
     dt2    37
     av1    70
     av2   113
     av3    60/;

PARAMETERS  COST(I)  cost in dollars

    /seat1  30000
     dt1    89000
     dt2   130000
     av1   100000
     av2   180000
     av3   250000/;


PARAMETERS  BENEFITS5(I)  the PV benefit of 5 years of
                          chosing change I

    /seat1  14953
     dt1     6428
     dt2     6428
     av1    49842
     av2    89716
     av3   124606/;

PARAMETERS  BENEFIT10(I)  the PV benefit of 10 years of
                          chosing change I

    /seat1  24237
     dt1    10419
```

```
      dt2     10419
      av1     80791
      av2    145425
      av3    201979/;

PARAMETERS  BENEFIT15(I)  the PV benefit of 15 years of
                          chosing change I

     /seat1  30000
      dt1    12896
      dt2    12896
      av1   100000
      av2   180000
      av3   250000/;


PARAMETERS  REQ(I,J)  equals 1 if poss. change I is in
                      type of change J

     /(seat1).seats                        1
      (dt1,dt2).drivetrain                 1
      (av1,av2,av3).glasscp                1/;

SCALARS  W  max allowable weight that can be added to
            the aircraft /218/
         C  max amount that can be spent on the aircraft
            /500000/;

VARIABLES

      X(I)       1 if component I is chosen
      Z          cost per aircraft given PV of 5 years
      K          cost per aircraft given PV of 10 years
      H          cost per aircraft given PV of 15 years

BINARY VARIABLE X;

OPTION OPTCR = 0

EQUATIONS

      BENYS5       total benefit in dollars for 5 years
      BENYS10      total benefit in dollars for 10 years
      BENYS15      total benefit in dollars for 15 years
      POUNDS       observing weight limitations
      SELECT       observing logical limitations;

      SELECT(J)..    SUM(I $REQ(I,J) ,X(I))        =E= 1;
      POUNDS..       SUM(I, WEIGHT(I)*X(I))        =L= W;
      BENYS5..       SUM(I, BENEFIT5(I)*X(I) -
                     COST(I)*X(I))    =E= Z;
```

```
85        BENYS10..       SUM(I, BENEFIT10(I)*X(I) -
                          COST(I)*X(I))  =E= K;
86        BENYS15..       SUM(I, BENEFIT15(I)*X(I) -
                          COST(I)*X(I))  =E= H;
87
88   MODEL OPT /ALL/; SOLVE OPT USING MIP MAXIMIZING Z;
89                    SOLVE OPT USING MIP MAXIMIZING K;
90                    SOLVE OPT USING MIP MAXIMIZING H;
91
92   DISPLAY POUNDS.L, Z.L, K.L, H.L;
```

```
SYMBOL        TYPE    REFERENCES

BENEFIT10     PARAM   DECLARED        35   DEFINED        37
REF          85
BENEFIT15     PARAM   DECLARED        44   DEFINED        46
REF          86
BENEFIT5      PARAM   DECLARED        26   DEFINED        28
REF          84
BENYS10        EQU     DECLARED          77   DEFINED           85
IMPL-ASN       88
                          89       90        REF       88
BENYS15        EQU     DECLARED          78   DEFINED           86
IMPL-ASN       88
                          89       90        REF       88
BENYS5         EQU     DECLARED          76   DEFINED           84
IMPL-ASN       88
                          89       90        REF       88
C             PARAM  DECLARED        61  DEFINED         61
COST           PARAM  DECLARED        16   DEFINED        18
REF          84
                          85       86
H              VAR     DECLARED       68 IMPL-ASN        88
89          90
                         REF       86         90         92
I              SET     DECLARED        4   DEFINED         4
REF           7
                          16       26         35         44
54          65
                        2*82      2*83       4*84       4*85
4*86
                     CONTROL       82         83         84
85          86
J              SET     DECLARED        5   DEFINED         5
REF          54
                          82   CONTROL        82
K              VAR     DECLARED       67 IMPL-ASN        88
89          90
                         REF       85         89         92
```

```
OPT            MODEL  DECLARED         88  DEFINED          88
IMPL-ASN        88
                          89        90       REF        88
89        90
POUNDS         EQU    DECLARED         79  DEFINED          83
IMPL-ASN        88
                          89        90       REF        88
92
REQ           PARAM  DECLARED        54  DEFINED         56
REF        82
SELECT         EQU    DECLARED         80  DEFINED          82
IMPL-ASN        88
                          89        90      REF        88
W             PARAM  DECLARED        60  DEFINED         60
REF        83
WEIGHT        PARAM  DECLARED         7  DEFINED          9
REF        83
X             VAR    DECLARED        65 IMPL-ASN        88
89        90
                         REF        70         82        83
2*84      2*85
                        2*86
Z             VAR    DECLARED        66 IMPL-ASN        88
89        90
                         REF        84        88        92
```

SETS

```
I             all possible changes
J             classification of changes
```

PARAMETERS

```
BENEFIT10     the PV benefit of 10 years of chosing change I
BENEFIT15     the PV benefit of 15 years of chosing change I
BENEFIT5      the PV benefit of 5 years of chosing change I
C             max amount that can be spent on the aircraft
COST          in dollars
REQ           equals 1 if poss. change I is in type of change J
W             max allowable weight that can be added to the
              aircraft
WEIGHT        in pounds
Symbol Listing
```

VARIABLES

```
H             cost per aircraft given PV of 15 years
K             cost per aircraft given PV of 10 years
```

```
X            1 if component I is chosen
Z            cost per aircraft given PV of 5 years


EQUATIONS

BENYS10      total benefit in dollars for 10 years
BENYS15      total benefit in dollars for 15 years
BENYS5       total benefit in dollars for 5 years
POUNDS       observing weight limitations
SELECT       observing logical limitations


MODELS

OPT


COMPILATION TIME     =          0.390 SECONDS          VERID
MW2-00-037

Equation Listing    SOLVE OPT USING MIP FROM LINE 88


---- BENYS5       =E=  total benefit in dollars for 5 years


BENYS5..   - 15047*X(SEAT1) - 82572*X(DT1) - 123572*X(DT2) -
50158*X(AV1)

      - 90284*X(AV2) - 125394*X(AV3) - Z =E= 0 ; (LHS = 0)


---- BENYS10      =E=  total benefit in dollars for 10 years


BENYS10..   - 5763*X(SEAT1) - 78581*X(DT1) - 119581*X(DT2) -
              19209*X(AV1) - 34575*X(AV2) - 48021*X(AV3) - K
              =E= 0 ; (LHS = 0)


---- BENYS15      =E=  total benefit in dollars for 15 years


BENYS15..   - 76104*X(DT1) - 117104*X(DT2) - H =E= 0 ;
              (LHS = 0)


---- POUNDS       =L=  observing weight limitations
```

```
POUNDS..  22*X(SEAT1) + 14*X(DT1) + 37*X(DT2) + 70*X(AV1) +
          113*X(AV2) + 60*X(AV3) =L= 218 ; (LHS = 0)


---- SELECT      =E=  observing logical limitations


SELECT(SEATS)..  X(SEAT1) =E= 1 ; (LHS = 0 ***)


SELECT(DRIVETRAIN)..  X(DT1) + X(DT2) =E= 1 ; (LHS = 0 ***)


SELECT(GLASSCP)..  X(AV1) + X(AV2) + X(AV3) =E= 1 ;
                   (LHS = 0 ***)

Column Listing     SOLVE OPT USING MIP FROM LINE 88


---- X          1 if component I is chosen


X(SEAT1)
                (.LO, .L, .UP = 0, 0, 1)
    -15047      BENYS5
     -5763      BENYS10
        22      POUNDS
         1      SELECT(SEATS)

X(DT1)
                (.LO, .L, .UP = 0, 0, 1)
    -82572      BENYS5
    -78581      BENYS10
    -76104      BENYS15
        14      POUNDS
         1      SELECT(DRIVETRAIN)

X(DT2)
                (.LO, .L, .UP = 0, 0, 1)
   -123572      BENYS5
   -119581      BENYS10
   -117104      BENYS15
        37      POUNDS
         1      SELECT(DRIVETRAIN)

REMAINING 3 ENTRIES SKIPPED


---- Z          cost per aircraft given PV of 5 years
```

```
Z
                   (.LO, .L, .UP =  -INF, 0,  +INF)
       -1          BENYS5

---- K             cost per aircraft given PV of 10 years

K
                   (.LO, .L, .UP =  -INF, 0,  +INF)
       -1          BENYS10

---- H             cost per aircraft given PV of 15 years

H
                   (.LO, .L, .UP =  -INF, 0,  +INF)
       -1          BENYS15

Model Statistics     SOLVE OPT USING MIP FROM LINE 88

MODEL STATISTICS

BLOCKS OF EQUATIONS          5     SINGLE EQUATIONS          7
BLOCKS OF VARIABLES          4     SINGLE VARIABLES          9
NON ZERO ELEMENTS           29     DISCRETE VARIABLES        6

GENERATION TIME       =         0.940 SECONDS


EXECUTION TIME        =         1.040 SECONDS          VERID
MW2-00-037

STEP SUMMARY:       0.490 STARTUP
                    0.390 COMPILATION
                    1.040 EXECUTION
                    1.870 CLOSEDOWN
                    3.790 TOTAL SECONDS

Solution Report      SOLVE OPT USING MIP FROM LINE 88

                  S O L V E      S U M A R Y

     MODEL    OPT                        OBJECTIVE  Z
     TYPE     MIP                        DIRECTION  MAXIMIZE
     SOLVER   ZOOM                       FROM LINE  88

**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        1 OPTIMAL
**** OBJECTIVE VALUE            -147777.0000
```

RESOURCE USAGE, LIMIT	0.220	1000.000
ITERATION COUNT, LIMIT	7	1000

Z O M / X M P --- 386 Version 2.2 Nov 1990

Dr Roy E. Marsten and Dr Jaya Singhal,
XMP Optimization Software Inc.
Tucson, Arizona

Work space allocated -- 0.01 Mb

	Iterations	Time
Initial LP	7	0.00
Heuristic	0	0.00
Branch and bound	0	0.00
Final LP	0	0.00

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU BENYS5	..	.	.	-1.000
---- EQU BENYS10	.	.	.	EPS
---- EQU BENYS15	.	.	.	EPS
---- EQU POUNDS	-INF	106.000	218.000	.

BENYS5	total benefit in dollars for 5 years
BENYS10	total benefit in dollars for 10 years
BENYS15	total benefit in dollars for 15 years
POUNDS	observing weight limitations

---- EQU SELECT observing logical limitations

	LOWER	LEVEL	UPPER	MARGINAL
SEATS	1.000	1.000	1.000	-1.505E+4
DRIVETRAIN	1.000	1.000	1.000	-8.257E+4
GLASSCP	1.000	1.000	1.000	-5.016E+4

---- VAR X 1 if component I is chosen

	LOWER	LEVEL	UPPER	MARGINAL
SEAT1	.	1.000	1.000	.
DT1	.	1.000	1.000	.

```
DT2           .             .           1.000 -4.100E+4
AV1           .          1.000          1.000      .
AV2           .             .           1.000 -4.013E+4
AV3           .             .           1.000 -7.524E+4

                          LOWER     LEVEL     UPPER    MARGINAL

---- VAR Z                -INF   -1.478E+5    +INF        .

---- VAR K                -INF   -1.036E+5    +INF        .

---- VAR H                -INF   -7.610E+4    +INF        .


  Z          cost per aircraft given PV of 5 years
  K          cost per aircraft given PV of 10 years
  H          cost per aircraft given PV of 15 years


**** REPORT SUMMARY :         0     NONOPT
                              0 INFEASIBLE
                              0  UNBOUNDED

Equation Listing    SOLVE OPT USING MIP FROM LINE 89


---- BENYS5       =E=  total benefit in dollars for 5 years


BENYS5..   - 15047*X(SEAT1) - 82572*X(DT1) - 123572*X(DT2) -
           50158*X(AV1) - 90284*X(AV2) - 125394*X(AV3) - Z
           =E= 0 ; (LHS = 0)


---- BENYS10      =E=  total benefit in dollars for 10 years


BENYS10..   - 5763*X(SEAT1) - 78581*X(DT1) - 119581*X(DT2) -
            19209*X(AV1) - 34575*X(AV2) - 48021*X(AV3) - K
            =E= 0 ; (LHS = 0)


---- BENYS15      =E=  total benefit in dollars for 15 years


BENYS15..   - 76104*X(DT1) - 117104*X(DT2) - H =E= 0 ;
            (LHS = 0)


---- POUNDS       =L=  observing weight limitations
```

```
POUNDS..  22*X(SEAT1) + 14*X(DT1) + 37*X(DT2) + 70*X(AV1) +
          113*X(AV2) + 60*X(AV3) =L= 218 ; (LHS = 106)


---- SELECT      =E=  observing logical limitations


SELECT(SEATS)..  X(SEAT1) =E= 1 ; (LHS = 1)


SELECT(DRIVETRAIN)..  X(DT1) + X(DT2) =E= 1 ; (LHS = 1)


SELECT(GLASSCP)..  X(AV1) + X(AV2) + X(AV3) =E= 1 ; (LHS = 1)

Column Listing      SOLVE OPT USING MIP FROM LINE 89


---- X           1 if component I is chosen


X(SEAT1)
                (.LO, .L, .UP = 0, 1, 1)
   -15047       BENYS5
    -5763       BENYS10
       22       POUNDS
        1       SELECT(SEATS)

X(DT1)
                (.LO, .L, .UP = 0, 1, 1)
   -82572       BENYS5
   -78581       BENYS10
   -76104       BENYS15
       14       POUNDS
        1       SELECT(DRIVETRAIN)

X(DT2)
                (.LO, .L, .UP = 0, 0, 1)
  -123572       BENYS5
  -119581       BENYS10
  -117104       BENYS15
       37       POUNDS
        1       SELECT(DRIVETRAIN)

REMAINING 3 ENTRIES SKIPPED


---- Z           cost per aircraft given PV of 5 years
```

```
Z
                   (.LO, .L, .UP =  -INF, -147777,   +INF)
       -1          BENYS5


---- K             cost per aircraft given PV of 10 years


K
                   (.LO, .L, .UP =  -INF, -103553,   +INF)
       -1          BENYS10


---- H             cost per aircraft given PV of 15 years


H
                   (.LO, .L, .UP =  -INF, -76104,   +INF)
       -1          BENYS15

Model Statistics    SOLVE OPT USING MIP FROM LINE 89

MODEL STATISTICS

BLOCKS OF EQUATIONS        5     SINGLE EQUATIONS          7
BLOCKS OF VARIABLES        4     SINGLE VARIABLES          9
NON ZERO ELEMENTS         29     DISCRETE VARIABLES        6

GENERATION TIME      =        1.100 SECONDS


EXECUTION TIME       =          1.320 SECONDS          VERID
MW2-00-037

STEP SUMMARY:         0.760 STARTUP
                      0.000 COMPILATION
                      1.320 EXECUTION
                      2.250 CLOSEDOWN
                      4.330 TOTAL SECONDS

Solution Report     SOLVE OPT USING MIP FROM LINE 89

              S O L V E     S U M M A R Y

     MODEL    OPT                      OBJECTIVE  K
     TYPE     MIP                      DIRECTION  MAXIMIZE
     SOLVER   ZOOM                     FROM LINE  89

**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE           -103553.0000
```

RESOURCE USAGE, LIMIT	0.270	1000.000
ITERATION COUNT, LIMIT	7	1000

Z O O M / X M P --- 386 Version 2.2 Nov 1990

Dr Roy E. Marsten and Dr Jaya Singhal,
XMP Optimization Software Inc.
Tucson, Arizona

Work space allocated -- 0.01 Mb

	Iterations	Time
Initial LP	7	0.05
Heuristic	0	0.00
Branch and bound	0	0.00
Final LP	0	0.00

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU BENYS5	.	.	.	EPS
---- EQU BENYS10	.	.	.	-1.000
---- EQU BENYS15	.	.	.	EPS
---- EQU POUNDS	-INF	106.000	218.000	.

BENYS5	total benefit in dollars for 5 years
BENYS10	total benefit in dollars for 10 years
BENYS15	total benefit in dollars for 15 years
POUNDS	observing weight limitations

---- EQU SELECT observing logical limitations

	LOWER	LEVEL	UPPER	MARGINAL
SEATS	1.000	1.000	1.000	-5763.000
DRIVETRAIN	1.000	1.000	1.000	-7.858E+4
GLASSCP	1.000	1.000	1.000	-1.921E+4

---- VAR X 1 if component I is chosen

LOWER LEVEL UPPER MARGINAL

```
SEAT1        .        1.000     1.000       .
DT1          .        1.000     1.000       .
DT2          .          .       1.000 -4.100E+4
AV1          .        1.000     1.000       .
AV2          .          .       1.000 -1.537E+4
AV3          .          .       1.000 -2.881E+4

                           LOWER     LEVEL     UPPER    MARGINAL

---- VAR Z                 -INF  -1.478E+5     +INF        .

---- VAR K                 -INF  -1.036E+5     +INF        .

---- VAR H                 -INF  -7.610E+4     +INF        .

  Z          cost per aircraft given PV of 5 years
  K          cost per aircraft given PV of 10 years
  H          cost per aircraft given PV of 15 years

**** REPORT SUMMARY :          0     NONOPT
                              0 INFEASIBLE
                              0  UNBOUNDED

Equation Listing    SOLVE OPT USING MIP FROM LINE 90

---- BENYS5       =E=  total benefit in dollars for 5 years

BENYS5..   - 15047*X(SEAT1) - 82572*X(DT1) - 123572*X(DT2) -
           50158*X(AV1) - 90284*X(AV2) - 125394*X(AV3) - Z
           =E= 0 ; (LHS = 0)

---- BENYS10      =E=  total benefit in dollars for 10 years

BENYS10..   - 5763*X(SEAT1) - 78581*X(DT1) - 119581*X(DT2) -
            19209*X(AV1) - 34575*X(AV2) - 48021*X(AV3) - K
            =E= 0 ; (LHS = 0)

---- BENYS15      =E=  total benefit in dollars for 15 years

BENYS15..   - 76104*X(DT1) - 117104*X(DT2) - H =E= 0 ;
            (LHS = 0)
```

```
---- POUNDS       =L=  observing weight limitations

POUNDS..  22*X(SEAT1) + 14*X(DT1) + 37*X(DT2) + 70*X(AV1) +
          113*X(AV2) + 60*X(AV3) =L= 218 ; (LHS = 106)

---- SELECT       =E=  observing logical limitations

SELECT(SEATS)..  X(SEAT1) =E= 1 ; (LHS = 1)

SELECT(DRIVETRAIN)..  X(DT1) + X(DT2) =E= 1 ; (LHS = 1)

SELECT(GLASSCP)..  X(AV1) + X(AV2) + X(AV3) =E= 1 ; (LHS = 1)

Column Listing      SOLVE OPT USING MIP FROM LINE 90

---- X             1 if component I is chosen

X(SEAT1)
                   (.LO, .L, .UP = 0, 1, 1)
   -15047          BENYS5
    -5763          BENYS10
       22          POUNDS
        1          SELECT(SEATS)

X(DT1)
                   (.LO, .L, .UP = 0, 1, 1)
   -82572          BENYS5
   -78581          BENYS10
   -76104          BENYS15
       14          POUNDS
        1          SELECT(DRIVETRAIN)

X(DT2)
                   (.LO, .L, .UP = 0, 0, 1)
  -123572          BENYS5
  -119581          BENYS10
  -117104          BENYS15
       37          POUNDS
        1          SELECT(DRIVETRAIN)

REMAINING 3 ENTRIES SKIPPED

---- Z             cost per aircraft given PV of 5 years
```

```
Z
                (.LO, .L, .UP =  -INF, -147777,  +INF)
      -1        BENYS5

---- K          cost per aircraft given PV of 10 years

K
                (.LO, .L, .UP =  -INF, -103553,  +INF)
      -1        BENYS10

---- H          cost per aircraft given PV of 15 years

H
                (.LO, .L, .UP =  -INF, -76104,  +INF)
      -1        BENYS15

Model Statistics    SOLVE OPT USING MIP FROM LINE 90

MODEL STATISTICS

BLOCKS OF EQUATIONS        5     SINGLE EQUATIONS        7
BLOCKS OF VARIABLES        4     SINGLE VARIABLES        9
NON ZERO ELEMENTS         29     DISCRETE VARIABLES      6

GENERATION TIME      =        1.050 SECONDS


EXECUTION TIME        =        1.420 SECONDS          VERID
MW2-00-037

STEP SUMMARY:       0.720 STARTUP
                    0.000 COMPILATION
                    1.420 EXECUTION
                    2.150 CLOSEDOWN
                    4.290 TOTAL SECONDS

Solution Report     SOLVE OPT USING MIP FROM LINE 90

               S O L V E     S U M M A R Y

     MODEL    OPT                  OBJECTIVE  H
     TYPE     MIP                  DIRECTION  MAXIMIZE
     SOLVER   ZOOM                 FROM LINE  90

**** SOLVER STATUS      1 NORMAL COMPLETION
```

```
**** MODEL STATUS        1 OPTIMAL
**** OBJECTIVE VALUE               -76104.0000

 RESOURCE USAGE, LIMIT              0.270      1000.000
 ITERATION COUNT, LIMIT             6          1000


 Z O O M / X M P    ---    386 Version 2.2 Nov 1990

 Dr Roy E. Marsten and Dr Jaya Singhal,
 XMP Optimization Software Inc.
 Tucson, Arizona


 Work space allocated               --     0.01 Mb

                    Iterations      Time
 Initial LP                  6      0.00
 Heuristic                   0      0.00
 Branch and bound            0      0.00
 Final LP                    0      0.00

                            LOWER      LEVEL      UPPER    MARGINAL


---- EQU BENYS5               .          .          .         EPS

---- EQU BENYS10              .          .          .         EPS

---- EQU BENYS15              .          .          .       -1.000

---- EQU POUNDS             -INF     106.000    218.000        .

  BENYS5       total benefit in dollars for 5 years
  BENYS10      total benefit in dollars for 10 years
  BENYS15      total benefit in dollars for 15 years
  POUNDS       observing weight limitations

---- EQU SELECT      observing logical limitations

                 LOWER      LEVEL      UPPER    MARGINAL

SEATS            1.000      1.000      1.000       EPS
DRIVETRAIN       1.000      1.000      1.000  -7.610E+4
GLASSCP          1.000      1.000      1.000        .
```

```
---- VAR X            1 if component I is chosen

            LOWER      LEVEL      UPPER    MARGINAL

SEAT1         .        1.000      1.000        .
DT1           .        1.000      1.000        .
DT2           .          .        1.000  -4.100E+4
AV1           .        1.000      1.000       EPS
AV2           .          .        1.000       EPS
AV3           .          .        1.000       EPS

                          LOWER      LEVEL       UPPER     MARGINAL

---- VAR Z                -INF    -1.478E+5      +INF         .

---- VAR K                -INF    -1.036E+5      +INF         .

---- VAR H                -INF    -7.610E+4      +INF         .

  Z          cost per aircraft given PV of 5 years
  K          cost per aircraft given PV of 10 years
  H          cost per aircraft given PV of 15 years

**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED

E x e c u t i o n

----      92 EQUATION   POUNDS.L                       =       106.000
observing weight

limitations
             VARIABLE  Z.L                         =  -147777.000 cost
per aircraft

given PV of 5 years
             VARIABLE  K.L                         =  -103553.000 cost
per aircraft

given PV of 10 years
             VARIABLE  H.L                         =   -76104.000 cost
per aircraft

given PV of 15 years
```

```
EXECUTION TIME        =          0.280 SECONDS          VERID
MW2-00-037

USER: Course OA 4201, Non-linear programming
G910909-1746AX-MW2
      Richard E. Rosenthal, NAVPGS

**** FILE SUMMARY

INPUT       C:\GAMS225\OPT.GMS
OUTPUT      C:\GAMS225\OPT.LST

STEP SUMMARY:       0.770 STARTUP
                    0.000 COMPILATION
                    0.280 EXECUTION
                    0.000 CLOSEDOWN
                    1.050 TOTAL SECONDS
```

LIST OF REFERENCES

Chief of Naval Air Training Tentative Operational Requirement (TOR), Undergraduate Naval Helicopter Training System (UNHTS), 1990

Naval Air Development Interim Report, Code 6034, 1991

Naval Air Instruction (NAVAIRINST) 13130.1A

Naval Air Warfare Center TH-57B/C Navy Training Helicopter Service Life Assessment Program (SLAP) Proposal, 1991

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